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SECTION 25

COMPUTER APPLICATIONS IN THE ELECTRIC POWER INDUSTRY

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25.1 INTRODUCTION

25.1.1 Growth of Computer Applications

The power industry is engaged in the generation, transmission, and distribution of electrical energy which is obtained by conversion from other forms of energy such as coal, gas, oil, nuclear, water, or other renewable energy. These activities often include mining, rail transport, shipping, slurry pipelines, and storage of energy in many forms. Many electric utilities are also engaged in the transmission and distribution of gas.

In the first 90 years of its history, the industry expanded at a pace nearly twice that of the overall economy, doubling roughly every 10 years. During this period, real prices per kilowatt-hour

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decreased steadily because of generation, transmission, distribution, technical improvements, productivity increases, and stable fuel prices. Throughout the 1970s, increased fuel costs, limits in economies of scale, diminishing returns in technology improvement, and increased regulation costs led to increased kilowatthour costs and reduced demand growth.

The political and economic response to increasing costs has been a movement to smaller generator sizes, minimization of capital investment, and attempts to control costs by fostering competition in generation supply. Incentives were also established to reduce demands and increase load factors. Today power supply is diversifying away from large central station technologies and toward increased use and availability of the transmission system.

In scheduling its day-to-day operation, and in planning for its future growth, the industry has made extensive use of analytical tools and mathematical models which, through optimization and simulation, help in the decision-making process. As a consequence, the industry has long been one of the largest users of computers and among the most sophisticated in its modeling and computational techniques. This use is quite understandable when one considers the high cost of power system equipment, the complexity of power systems, and the severe operational, reliability, and environmental requirements on the electricity supply.

Computer applications have assisted the industry in achieving its objectives: reducing the cost of energy delivered to consumers, improving the quality of service, enhancing the quality of the environment, and extending the life of existing equipment. These objectives have been achieved as follows:

1. Since the industry is one in which capital investment is usually high (over 10% of total spending by the nation's industries), unit costs have been reduced by operating facilities closer to their design limits, allowing better utilization of equipment.
2. Unit costs also have been reduced by automation, allowing operation with fewer personnel, and by optimization, lowering fuel consumption per kilowatthour delivered.
3. Electricity cannot readily be stored; therefore, production and consumption must be simultaneous. Hence enough capacity is required to meet the maximum coincident demand or peak load of all customers. Interconnections between power systems provide important economies arising from different time patterns or diversity of use of the component systems in the network. They allow higher power system reliability at lower capital cost.
4. Quality of service has been improved by reducing the number, extent, and duration of service interruptions, thus providing a more reliable service.
5. Quality of environment has been maintained by operating facilities within acceptable bounds of emission, thermal discharge, waste disposal, and more effective land use.

Today the industry has reached a stage where computer systems are no longer merely an engineering tool. The effectiveness of computer applications is one of the key elements in achieving the basic functions associated with the planning, designing, construction, operation, and maintenance of the power system. In fact, engineering and computers have been integrated. This integration may be viewed as tending toward the construction of a utility industry information system. Such a system is shown in Fig. 25-1. It depicts a typical information system which may be viewed as a combination and integration of several functional information systems.

Such an information system can extend the company capabilities by making relevant and current information accessible to both technical and management personnel. Designs can be refined by using measured data or operations experience, projects can be monitored, revenue requirements can be predicted more closely, and the experience of operations can be reflected in the methods and criteria used in planning and engineering. The information system thus can provide meaningful data at proper times and locations to make decisions and concentrate resources in the most effective manner.

Computers and their applications are ubiquitous in electric utilities. As in most industries, the business and corporate uses are extensive. This section deals with the sophisticated engineering and operations applications of computers, which are often unique and specialized to the industry's goals and technical demands.

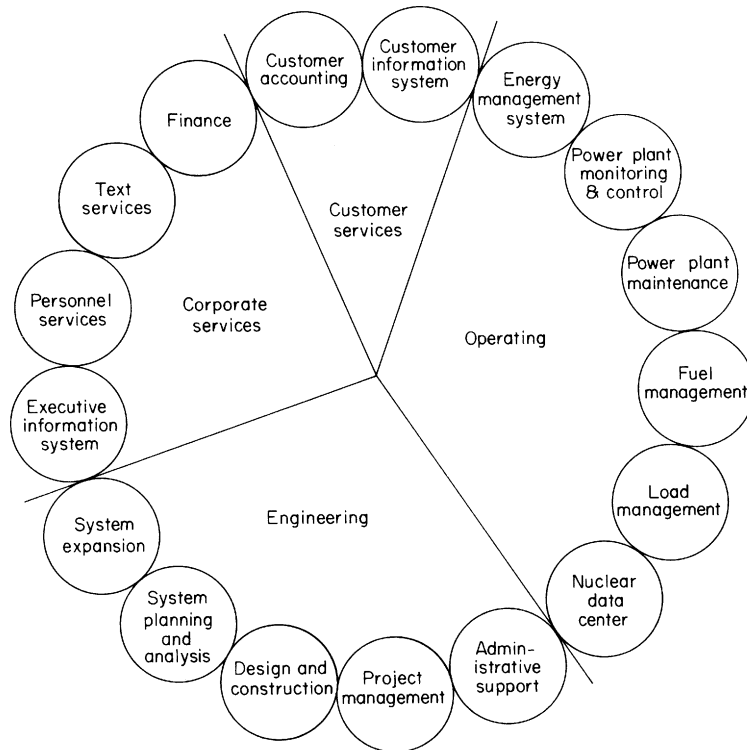


FIGURE 25-1 Electric utility information systems.

25.1.2 Goals of the Power Industry

The industry's purpose is to provide adequate, reliable, environmentally compatible electricity at reasonable cost with the ultimate goal of improving its productivity and net earnings. In spite of the differences between publicly and privately owned utilities, this goal is applicable to each, in different form. This goal is reached by pursuing a number of objectives as described below.

Improved Financial Management

- *Raising new capital.* Traditional electric utility companies and independent power producers are major utilizers of capital to finance and build new capacity, replace or renovate old equipment, and retrofit plants and delivery equipment for environmental and reliability considerations. Projected industry construction in the next decade runs into hundreds of billions of dollars. Competing demands for capital and its high cost encourage and justify precise planning, design, and operations.
- *Plant investment.* Utilities must spend very large sums in generating plants and transmission facilities. Present-day decisions on such additions, together with the proper selection of plant sites and the acquisition of transmission rights of way, have long-range financial implications affecting earnings. At present, the industry is experiencing difficulties in selection of plant sites and obtaining rights of way, licenses, and permits, with the results that the industry seldom obtains new plant sites and is forced to expand existing generating sites. Demand-side options must be properly weighed against generation expansion alternatives. Independent power producers (IPPs) must

make precise investments, and utilities must properly invest in facilities needed to utilize and accommodate IPPs. This situation compounds the problems of system modeling and system losses, and increases transmission system dependency.

- *Long-term contracts.* Fuel constitutes about 35% of the industry's total annual operating expenditures. A typical modern power plant consumes about 500 tons of coal each hour, and its average life is about 30 years. A nuclear power plant of a similar size requires an initial nuclear core costing hundreds of millions of dollars plus a significant annual refueling expenditure for the next 30 years. Independent power producers supply energy under contract for varied periods and conditions. The goal is to procure energy supply and these fossil and fissile fuels through long-term contracts providing a continuous supply of fuel at reasonable cost throughout the plant's 40- to 60-year life.
- *Growth through affiliation.* There have been a significant number of corporate mergers between large and small utilities. The goal in these affiliations is to meet the growth in demand for energy by taking advantage of economy of scale; consolidation of administration, engineering, construction, research, and development; and increasing reliability of bulk power supply.
- *Economy and reliability.* The industry has achieved significant improvement in economy of operations and in reliability of power systems either through direct operational pool functions or with contractual economical agreements.

Increased Revenue. For 30 years (1935 to 1965) utilities were, by lowering costs, reducing their rates and increasing sales. During this period of falling rates, owing to lags in regulatory rate adjustment, utilities enjoyed a higher revenue and were motivated to be efficient. The costs were reduced by the installation of larger generators, higher transmission voltages, lower fuel costs, and shifts to available gas and oil from coal.

From 1973 to 1990, the utilities went through a period of rising costs due to rises in fuel cost, environmental regulation, diminishing efficiency returns in technology (unit sizes and improvements), and investing in new technologies such as nuclear plants. During this rising-cost period, the regulatory lag in rate adjustments had an adverse economic impact, demanding detailed analysis of past and present operations and projection of future requirements by financial modeling, optimization schemes, and simulation techniques.

The expanded list of supply- and demand-side options and the desire to open transmission system access have made electric utility planning and operations much more complex. Construction delays and the desire to minimize capital expenditures have resulted in the electric power system being used in unexpected ways, and design safety margins must be reduced or stressed.

Reduced Cost. Cost reduction can be achieved by reducing investment per kilowatt of installation capacity for generation, transmission, and distribution and reducing operating cost per kilowatthour of energy delivered.

Reduced plant investment can be achieved by proper generation mix and location, increased transmission and distribution voltages, power pooling, interconnection planning, and coordination to gain further advantages of scale. Involved also are improved production and distribution facility utilization (i.e., capacity factor and load factor) through peak shaving, reserve sharing, load diversity, and distribution load balancing. Other means of reducing costs include designing facilities with more precision and reducing the factor of safety, reducing construction and inventory costs, and operating the facilities closer to their design limits.

Reduced operating expenditure can be achieved by adopting new technology that requires lower fuel costs, by improving conventional and established methods of higher energy conversion efficiencies, by reducing energy losses in transmission and distribution facilities, and by interchanging energy with more economical resources and different time zones in different seasons to take advantage of diversity.

Other means are producing and distributing electricity with fewer personnel; minimizing the labor force and material inventory required for maintenance, repairs, and restoration of generation, transmission, and distribution facilities; and reducing customer accounting, general accounting, and administrative expenses.

Improved Quality of Service. Among the requirements in this category are reducing the frequency, duration, and extent of outages in the power supply; reducing voltage and frequency discontinuities and sudden excursions (power-line disturbances) to sensitive electronic loads and digital equipment; and improving customer services through prompt response to inquiries, requests, or complaints. It is also important to maintain the power supply within prescribed ranges and specifications and to restore interruptions in service quickly.

Enhanced Environment. Means of improving environmental impact include reducing thermal discharge to natural bodies of water through the use of artificial lakes, cooling towers, and desalinization processes and advancing direct conversion of heat energy to electrical energy as by magnetohydrodynamics, thermionics, and fuel cells. Also involved in conventional systems are reducing the release of combustion products (sulfur dioxide, nitrogen oxides, carbon dioxide, and particulate matter) in the atmosphere; reducing the frequency, duration, and intensity of pollution concentrates in urban areas; and providing more productive uses for fly ash. Safer storage of nuclear waste is of primary importance.

In the design of systems, selecting remote or underground sites for generating stations, improving aesthetics by the increased use of underground distribution facilities, and beautifying transmission towers and lines in harmony with the countryside are all being urged by environmentalists. Modern transmission- and distribution-line designs reduce magnetic and electric fields in consideration of possible health effects.

Improved Employee Skill

- **Labor.** In earlier years, the power industry had a labor force of about half a million employees, a small force when compared with its very high output. In the 1970s, while the generating capacity doubled, the number of employees remained substantially the same. This was achieved through the operation of larger installations with fewer personnel, centralized control of generation and transmission, unattended substations, and minimizing maintenance and repair crews by automating dispatch procedures. This trend no longer holds.
- **Professional.** The design and construction of large installations such as generating stations and extra-high-voltage lines are often contracted out and are engineered and supervised by consulting firms. Thus, in effect, the consultants provide a common professional pool for all utilities. The electrical manufacturers have been primarily responsible for research and development of the industry, and the practice of accepting turnkey contracts is common. Thus manufacturers also provide a common pool of labor.

However, the advent of nuclear power, extra-high-voltage, and environmental limitations requires significant changes in utility systems and calls for an increase in both the quality and quantity of professional labor. The industry recognizes the need for this rapid increase in in-house skill. This can be provided by (1) improving the productivity and effectiveness of employees, (2) merging and affiliating with neighboring companies forming regional groups, and (3) maintaining aggressive in-house research and development as well as supporting institutions of higher learning and research organizations by sponsoring research and development efforts.

25.1.3 Spectrum of Computer Usage

A review of engineering and operating computer applications indicates that they fall within several broad categories, as shown in Fig. 25-2 and as described below.

System Expansion. These applications are related to 20-, 10-, and 5-year construction programs and cover planning, design, and construction of new facilities. These functions are performed at least once a year and use long-range load forecasts and other predictions as input data. Competitive pressures and complexity of expansion options demand that engineers have sophisticated interactive computer tools, decision-support and communication systems, and report-generating mechanisms.

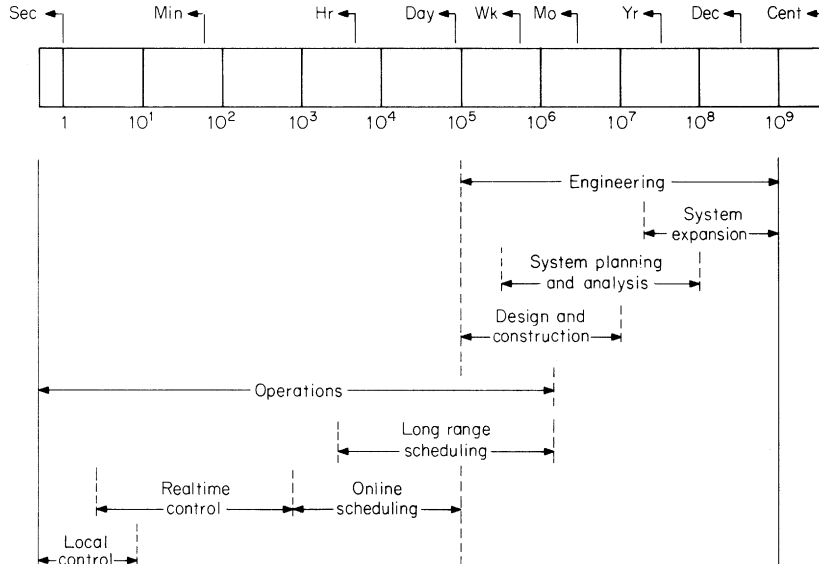


FIGURE 25-2 Spectrum of computer use.

System Planning and Analysis. These applications deal with 3- and 1-year construction of new facilities and the economic and reliable operation of these additions in conjunction with other interconnected power systems. Nuclear fuel management, annual hydrothermal coordination, and coordination for firm transmission and generation planning are among these functions. Because these programs are more frequently called on, they normally reside on disk storage devices. Thus only changes in data and programs need be entered when using specific programs.

Long-Range Scheduling (Operating). These applications are related to annual, monthly, and daily operation of the power system. In this category are transmission and generation maintenance scheduling, unit commitment and withdrawal, and other functions dealing with both reliability and economy of operation. Electric power systems are more complex and stressed than ever before. Maintenance of reliability and cost reduction require fast interactive computation in order to evaluate contingencies, operating options, and limits.

On-Line Scheduling. These applications are related to security monitoring and determination of reserve indexes and hourly data recording. These schedules are performed at least once an hour, although some applications such as pumped storage scheduling are performed weekly and daily. They are based on historical data but also need current power system data such as facilities in and out of operation, generation outputs, and line flows. Therefore, they require direct data flow into the computer. The results, however, are presented to the user for consideration and execution. Because of the scheduling nature of these applications, very fast data acquisition is not a prerequisite; however, accuracy and timeliness of schedules are related to the extent that they include direct data acquisition.

Real-Time Control. These regulating functions are carried out to meet the changing demands on the power system. Power system monitoring, security assessment, and display, rescheduling, and control of system frequency, tie-line flows, voltage conditions, and transmission flows are examples of this category. Other examples are closed-loop automatic control of generating units and interchange scheduling with neighboring companies and pool areas. These functions are performed in a

time range of a few seconds to several minutes and therefore not only require direct data flows into the central computer but, in addition, require signals from the computer to the various remote controllers and actuators.

Local Control. These applications require a response speed beyond the capability of central computer control and related communication. Most of these functions are initiated immediately after a fault develops or a variable exceeds certain limits. Their objective is to react quickly and correct the situation or to isolate and contain a disturbance. These functions are performed in the few milliseconds to several seconds range and can best be handled by local computers: (1) by directly sensing variables and controlling through actuators (e.g., direct digital control of boilers or digital relaying of the substations) and (2) by superimposing the computer on the local controllers or protective relays in order to reset their operating positions. The latter applications are in the 1- to 10-s range.

The computational requirements shown in Fig. 25-2 cover both engineering and operating functions. These areas of computer activities are interrelated. From the preceding discussion it is clear that the power system operating functions do not have to be performed necessarily in real time.

25.2 ENGINEERING APPLICATIONS

As the electric utility industry has grown in size and complexity, modifications and additions to existing electric power networks have become increasingly costly. Therefore, it is vital that different design possibilities for additions and modifications to the network be studied in detail to determine their effect on the network, their effect during abnormal operating conditions, and their applicability as a flexible solution to current and future power demands.

The design and construction of planned facilities involves the efforts of a sizable engineering staff and a substantial investment in facilities. To provide support in these activities, computer programs have been developed for analysis of specified designs. The application of these programs contributes to the installation of reliable and economic facilities. The major engineering applications are shown in Fig. 25-1 and summarized below.

25.2.1 System Expansion

The system-expansion applications (Fig. 25-3) support the long-term (5 to 20 years) planning function for generation and transmission of power. The system-expansion application area represents the typical decision support environment in that many cases are produced and a variety of options and strategies are considered in the planning process. This area controls large common data sets from multiple sources. Lengthy reports are produced for internal documentation and regulation approval. In the past, most of the processing was batch-oriented because of the length of computation. Today on-line dialog with the applications is feasible and essential for evaluation of alternatives.

With the current economic outlook, the majority of emphasis in the industry will be to develop more efficient use of existing facilities rather than new construction. Load forecasting and production costing are becoming the most significant items in system expansion to predict load requirements and operating costs. Tradeoffs between expansion and new facilities are increasingly important. The applications in this category are as follows:

Load Forecasting. This application is the basis for all planning functions. It utilizes historical data, trends, economic factors, and residential and industrial projections by geographic area to produce load requirements and load duration plots by area. The effects of demand-side management are incorporated to evaluate the most cost-effective options. It also predicts the load factor.

Generation Mix Analysis. This plans the optimal mix of peaking, base-loaded, or independent power producer units; fuel type; and location of units to meet the future load requirements. It also provides a buy-and-sell analysis and accounts for reliability of generation.

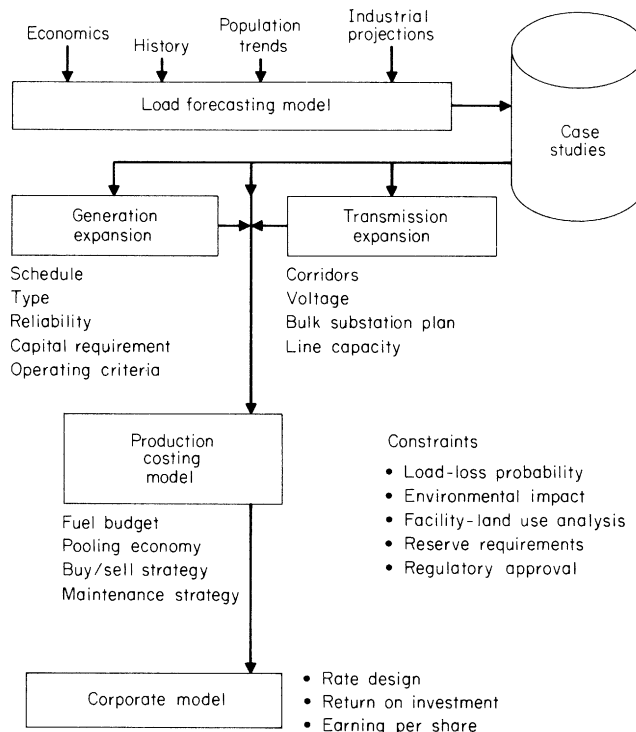


FIGURE 25-3 System expansion applications.

Production Costing. This simulates the operation of the existing and planned generation facilities for several years in order to predict the fuel budget. It meets the load forecast and accounts for the generation availability and the hour-by-hour dispatch of generation. New techniques use statistical approaches versus detailed models.

Loss of Load Probability. This accounts for unit availability and the reserve requirement to produce a probability of loss of specific loads.

Voltage Level Analysis. This application is a tool to plan voltage levels of existing and planned transmission facilities. It provides tradeoffs of network losses versus capital requirements.

Environmental and Facility Land-Use Analysis. This set of applications assists the planner in locating plants, substations, transmission towers, and lines. Tradeoffs considered are expansion versus new facilities, right-of-way utilization, and environmental impact of planned facilities. Tighter environmental controls are increasingly affecting expansion and operating plans.

25.2.2 System Planning and Analysis

This application area supports the short-term planning process and provides tools for analyzing incremental expansion. System planning and analysis applications are high in floating-point content and represent a significant computational requirement. Many cases are analyzed, and there is a rapid turnaround requirement. While there is on-line dialog with the application and it is common to

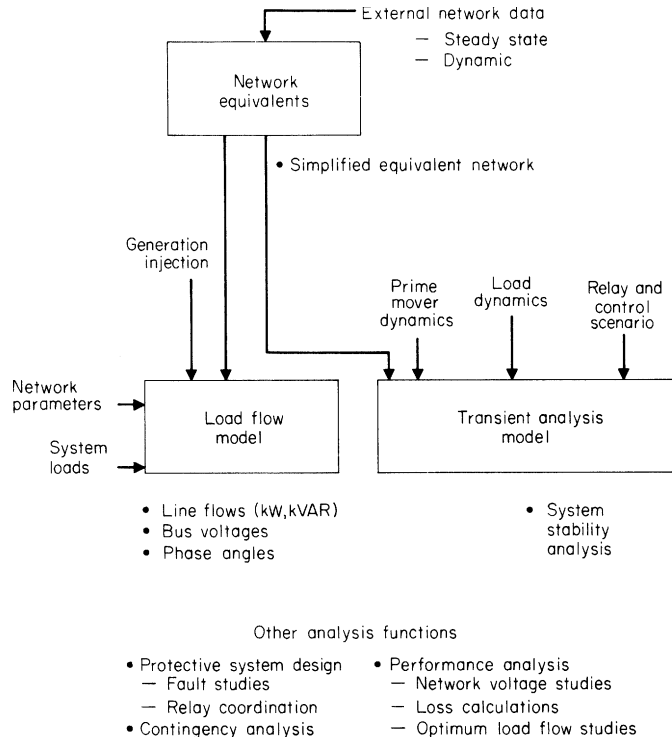


FIGURE 25-4 System planning and analysis applications.

provide on-line display and edit of results, the trend is to use interactive graphics in all phases of this decision support process. The specific applications are shown in Fig. 25-4 and described below.

Load Flow. The load-flow program is one of the major tools of system planning and is utilized extensively. Important to the system planner are that input data errors be minimized and that there be an easy and rapid turnaround for answers when the frequency of program use is high. To accomplish this, interactive capability is provided with the ability to store base cases or numerous power system models on the computer's disks. The storage capability provides many different cases that the planning engineer can access for studying or varying a particular system condition. Load flow enables the power system planning engineer to simulate and solve various power system expansion alternatives in an interactive mode. It utilizes a graphics color terminal specified with a special set of graphic characters that presents results in the form of system on-line diagrams. The multicolor feature of the terminal is used to indicate heavily loaded lines, bus voltages outside normal limits, and open circuit breakers. The engineer working at such a terminal may, with a mouse and alphanumeric keyboard, remove, add, or change elements of the system being studied and request a solution from the host computer.

The simulation programs associated with the load flow program are a system of linked programs that have the following capabilities:

1. Basic programs involving calculation of voltages, power flows, angles, and interchanges between areas of a power system.
2. A network reduction program to represent large networks as equivalents in conjunction with the specified area to be studied.

3. A distribution-factors program that indicates the sensitivity of response of the various circuits to outages of specified transmission lines, used to predict thermal limits with linear (superposition) techniques.
4. The series of programs associated with the stored load flow files which permit accessing a particular case, deleting a case, adding a case, and changing a case.
5. The var allocation program which selects the minimum amount of kilovars of compensation necessary to maintain bus voltages within specified limits under normal and/or emergency conditions. Optimal power flow (OPF) is a versatile alternative for var planning, economic dispatch, and performance improvement.

Transient Analysis. This is a large, dynamic simulation of the generation and transmission network in the transient state. It models the dynamics of synchronous machines after a system fault condition. It produces network stability information that guides the engineer in design of the network and its protective system.

Protective System Design. This application automates the work of the relay engineer in designing the protective system. It includes fault and relay-coordination studies and calculates complex relay settings.

Switching Surge Analysis. This program calculates the voltage and current transients resulting from switching surges and lightning strikes.

Contingency Analysis. This is the off-line analysis of predetermined outages and network contingencies. It is used by planning in design studies. Results are used as input to the operating area for guidance during problem or alert conditions. When combined with OPF, this is referred to as *security-constrained optimization* (SCO).

Performance Analysis. This attempts to satisfy voltage level criteria for the network and specific consumers while minimizing network losses.

25.2.3 Design and Construction

This function includes all routine applications associated with the design and construction of power plants, transmission facilities, substations, service centers, and distribution facilities. Electric utility companies on average spend more for new construction each year than any other industry. Although their primary objective is the usual production and sale of a product, they must be concerned with a large capital investment program. Efficient planning, scheduling, and control of labor and material resources are necessary if customer demand is to be met and at the same time a fair rate of return is to be provided on the investment.

Major Programs. Design and construction is a multidiscipline activity that employs computer applications dealing with electrical, mechanical, and civil engineering functions. A partial listing of specific applications is described below.

The *tower analysis* program provides a summary of the maximum tension and maximum compression for each member of a three-dimensional structure over the entire load range specified. This program also spots structure locations, plots a profile of the transmission line, and calculates sag, insulator swing, and ground clearance.

Line sag calculates sag and tension of conductors under a given situation.

Branch circuit design uses the load, distance, number of cables in a raceway, wire temperature rating, motor-starting, and full-load amps to compute the voltage drops and sizes of breakers, cable, and conduit in a circuit.

Structural design programs are used to design concrete and steel structures using as input the structure configuration and loads such as floor, roof, and impact.

The *structural steel framing* program is used to design the beams, columns, girders, and base-plates of power plant structures.

The *foundation-slab analysis* program is used to design large, complex foundation mats. The results permit evaluation of various slab thicknesses, soil bearing pressures, shears and bending moments, and reinforcement areas.

The *concrete stack analysis* program is used to analyze proposed stacks by determining loadings, resulting stresses, and required steel reinforcement. This program is used extensively in the design of very tall concrete stacks selected for new power plants.

Piping programs are used to perform stress analysis of piping systems and determine hanger design information. The *power plant piping* program analyzes the flexibility of a piping system under the influence of temperature.

The *cable routing* program provides the shortest cable route between nodes, percent raceway fill, and number of cables in a tray or raceway.

Interference analysis resolves the interference between pipe, cable tray, and structures occupying the same space.

The *heating, ventilating, and air-conditioning design* program uses thermal loads and the building configuration to calculate the size of refrigeration equipment and ductwork required.

Fluid dynamics analysis analyzes piping systems for pressure drop, flow distribution, and power requirements.

Hydrologic analysis is used to determine seepage flow networks, underground flow, and rainfall and runoff drainage for culvert and bridge size and design.

Earthwork design is used to design embankments and roadways and perform settlement and embankment stability analysis.

Geotechnical evaluation is used to evaluate soil testing results and determine the strength and swell of soil for dam and foundation design.

Foundation design programs are used to design foundation pile, pier, mat, and spread footing.

A *statistical analysis of equipment failures* means data collected on the frequency and cause of equipment failure is used to determine the likelihood of similar failures in the future based on various changes. The purpose of establishing an equipment operation database is to record and summarize the specific causes of service interruption to generation, transmission, distribution, and communication system equipment as well as to customers. The data provide the basis for designing new systems to specific reliability levels, monitoring equipment and manufacturer adherence to desired availability standards, and carrying out maintenance scheduling activities.

The database consists of a main file for each major equipment category and supplementary files which supply input to a family of programs designed to provide the engineers with periodic statistical reports. Engineers also have the ability to retrieve from this database any combination of data of their own choosing.

Transformer load management consists of a series of programs to process manufacturing performance data for distribution transformers and derive an economic evaluation based on unit cost and expected loss contributions over the expected lifetime. Since distribution transformers represent such a substantial proportion of system investment, it is imperative that they be utilized to their fullest economic capability.

A large percentage of distribution transformers are nominally underloaded; that is, they are oversized for the load being served and hence waste money through overinvestment and excessive core losses. Overloaded transformers also waste money in terms of copper losses, loss of life, fuse and transformer burnouts and replacements, and the investigation of low-voltage complaints.

Drafting includes engineering sketches and standard symbols used to lay out a drawing on a terminal and the results are printed or plotted. Included in this application are computer-aided design and drafting packages.

Economic analysis is used to make economic decisions between alternative sets of system designs or equipment.

Most of the preceding applications require common data. The trend is to treat the data as a corporate resource and to capture and maintain them in a common database. This provides for consistency of data, avoids duplication, and minimizes errors due to entry of the same data in different programs. This common database can then be used by many of the design and construction programs.

Resource-management subsystems that support the design and construction applications are briefly described below. The purpose of resource management is to help utilities in more effective utilization, control, and management of their basic resource (people, equipment, and facilities) in the distribution system.

Distribution Construction Information System. This application supports the management of new investment and maintenance in the distribution area. It provides information for planning, scheduling, and controlling equipment, labor, and material resources and becomes a tool to assist public utilities in providing consistent service and meeting customer demands while realizing fair rates of return on capital investment.

The term *distribution construction* refers to the entire process of work requesting, design, scheduling, reporting, and closing of that portion of the facilities closest in service to customers. New distribution work stems from three types of activity: system maintenance and improvement requirements, customer requests, and inspections or surveys.

For many utilities the distribution system alone represents close to one-third of the total capital investment. Thus it is not surprising to find continuing concern with the process by which facilities are constructed and maintained and by which costs are transferred to property accounts or charged to expense appropriations. This concern is often focused on improving the distribution work process to support the planning, design, scheduling, controlling, and tracking of jobs. Such improvements are undertaken to obtain a more effective and efficient work process leading to an earlier plant-in-service and to improving the utilization of the many resources devoted to distribution construction, maintenance, and operating tasks.

Computerizing the distribution work process is desirable because of the significant capital investment and expense components of utility costs and because the work process has characteristics that lend themselves to a high degree of computerization and to improved productivity and control.

Distribution Facilities Information System. This application provides the information required to plan, control, maintain, locate, account for, and manage the distribution facilities of an electric utility. It is also referred to as an *automated mapping and facilities management system*. When combined with terrain and other landmark information, it is referred to as a *geographic information system* (GIS). It is composed of a graphics system and a database system.

The graphics system provides the interactive functions required to capture information needed to maintain a database for facilities by locations. The user is required to define to the graphics system the facilities and the data elements which are associated with them. This includes its data fields, the pictures that are displayed on a map to represent it, and the connectivity requirements, if it is a network facility.

The graphics system employs a graphics workstation composed of at least one high-resolution display, an alphanumeric display, a keyboard, a mouse, and various hard-copy devices. This workstation is used to enter geographically related data, making it subsequently possible to display the data pictorially (maps), interact with the display (zoom in, window, edit, etc.), display facilities data and alter them, or to make additions or revisions. These are functions that formerly involved manual drafting and filing methods.

Maps or data generated at the workstation may be stored in a common facilities database accessible to many users. The manner in which these data are stored varies. Some systems are able to retrieve only the map facets that were entered; the user must establish the relationship between adjoining facets. In other systems the data exist as a continuous network, and the user requests only the portion and type of data needed. Storage techniques based on the common corporate database management system are becoming prevalent because of the common requirements for facilities data by many departments throughout the company.

The production of maps, diagrams, and pictures is a by-product of this system. Of far greater importance is the network relationship of the facilities data. This allows such applications as feeder analysis, transformer load management, fuse coordination, branch circuit design, and fault current calculations to be executed using the common facilities database.

Material-Management Information System. This system is used to plan for and control the flow of materials in and out of the company. A material items database may be accessed by many departments for multiple purposes. The main subsystems are stores operations, materials planning, and purchasing.

Stores operations relates to all day-to-day activities within the warehouse location. Included in these are functions such as stock inquiry handling, recording of stores transactions (receipts, issues), item location management, order and requisition initiation, and material reservation and allocation control.

Materials planning refers to the control and management of an inventory, both repairable and expendable parts. The functions under this application are acquisition analysis, item forecasting, materials requirements planning, reporting, and stock taking control.

The purchasing area includes the functions of ordering material from the suppliers and transferring to the inventory on receipt of the material. The functions within this are purchase order writing, quotation preparation, receiving, returns, implementation, quality assurance, vendor performance analysis, and invoice matching.

25.2.4 Project Management

The objective of project management is to control project costs and schedules in the maintenance and construction of power system facilities. Power engineers have used manual project information systems for years. Now there is rapid movement to automation of project control with provisions for on-line display and edit of results.

Project management in the engineering departments includes project control, project scheduling, and resource optimization tools. These tools are required to manage small procurement projects. However, they also could be major, long-term projects such as construction of a facility, installation of a major program, or daily tracking of activities within a department. Automated techniques, taking into consideration the control of time, resources, and costs, allow more productive utilization of project management personnel and stricter control of projects than manual methods. There are three major components of a project management system:

1. *Critical-path method.* A network represents a project which consists of a mixture of serial and parallel activities and employs a combination of personnel resources, materials, and facilities. When time is associated with each activity within a network, critical-path methodology can be used to analyze the network and determine the longest time path to completion of the project. All other time paths through the network will then have some slack in terms of the critical path.
2. *Resource management.* Project management and scheduling provides the means to plan and control a variety of projects. These systems permit tasks to be scheduled, resources assigned, costs allocated, and progress reported. Using this process, management can address identified problem areas and adjust its plans accordingly.
3. *Project costing and estimating.* Cost control techniques involve the ability to estimate and assign costs for labor, material, facilities, test equipment, and other resources to all activities comprising the execution of all phases of a project. In addition, some application programs permit extending rates; accommodate matrix and other organization structures; compute general, administrative, and overhead expenses; and summarize project costs over selected parts of projects as well as multiproject groups.

25.2.5 Administrative Support

Administrative functions have been automated to serve the various requirements of engineering departments. Because these requirements are common throughout the company, integrated or common solutions are often used. Administrative support typically falls into the following categories.

Text processing is the preparation, output, and data entry and editing of text using an interactive host-based or stand-alone computer system. This service may be used by a secretary to compose a

letter or modify an existing memo. It may also be used directly by an engineer for notes, lists, progress reports, and general documentation. Text processing in a power company is used to prepare and maintain operating standards and procedures, standard material lists, nuclear records, training manuals, maintenance and safety procedures, regulatory reports, and specifications.

Administrative processing allows the user to manage electronic document images. It includes activities such as copying and reproducing, document distribution, records file processing, mailing, and office correspondence. Documents may be filed on disk, searched for, and retrieved. Document search may be by name or by complex search parameters as in nuclear records.

Other administrative services provide a convenient means for writing notes, reminders, messages, and appointment records. Typical functions include calendaring, tickler file (diary), meeting schedule, phone list, and to-do lists.

Text and data integration applications provide the ability to include data created outside of text applications to form reports and letters. These may be used for the creation of manuals which include specification data to reduce redundant keystrokes and increase accuracy.

Communications applications provide an informal and unstructured method of communication within an organization. This provides the means of handling messages that might otherwise require a phone call or memo. It also allows for distribution to multiple locations and receipt acknowledgment.

Personal computing provides engineers with the tools, packages, and techniques that allow them to enter and manipulate data and accomplish in hours what might otherwise take weeks. The intelligent work station provides local processing, user-friendly interfaces, and access to host applications. Many times, all applications programs can be executed on a personal computer.

Presentation graphics applications are used to present data in a pictorial form. The graphics may be displayed on a terminal or converted to a hard copy using a printer, plotter, terminal copier, or an attached camera device. Typical uses include the presentation of engineering or statistical data as line, bar, or pie charts, preparation of foils for a presentation, or drawing sketches or diagrams for inclusion in a publication.

25.2.6 Power Market Computer Simulation

Computer simulation has been a powerful tool for electric power system researchers and operators to study the system behavior under various conditions. The increasing complexity of power systems and interconnections to other infrastructures, vulnerabilities to cascading failures, interactive and large-scale nature of these networks, coupled with advances in modeling, computational methods, software technologies, simulations, control of networks, and economic aspects, have driven the further development of power system computer simulation tools. With the advent of deregulation, unbundling, and competition in the electric power industry, new software tools are needed to improve the efficiency of that network without seriously diminishing its reliability.

Power market simulator is a software tool that helps clients simulate hedging strategies in electricity markets before the strategies are put into practice and account for market contingencies in market operations and production. Capable of modeling complex power market interactions, this software tool will also allow market participants to train their staff to effectively address market scenarios that, until now, could not be handled confidently. The market simulator is useful in helping to perform a variety of functions:

- System contingency analysis to develop hedging strategies for system contingencies
- Market contingency analysis to develop hedging strategies for market contingencies, such as changes in price caps, bidding mechanisms, and new entrants
- Congestion management to develop hedging strategies for congestion charges
- Planning and expansion to demonstrate improved efficiency, reliability, and service from planned generation expansion in specific network locations
- Interregional coordination to simulate seams issues and help test strategies for coordinating production across multiple markets

25.3 OPERATING APPLICATIONS

The prime concern of the electric utility industry is to meet the consumer's power demand at all times and under all conditions. Electric utilities are continually seeking and have been most receptive to every available technique which would reduce the capital investment per kilowatt of installation, reduce the operating expenditures per kilowatthour of energy delivered, and improve the quality of service to the consumer.

Computer systems can be found in use at all levels of operation in power systems. At the generating-plant level, for example, they are used to control and monitor unit startup and operating conditions. In bulk power substations they serve such functions as monitoring, event recording, and switching. And at the system operating center level, they help to improve the economy of operation, improve the quality of service, and simplify system operation. The major computer applications for the operating area of a utility are shown in Fig. 25-1 and briefly described below.

25.3.1 Supervisory Control and Data Acquisition System

The electric utility SCADA (Supervisory Control and Data Acquisition) system is now a mainstay. Most electric utilities have means to monitor their power system activity and control substation equipment from a central location that would be classified as a SCADA system. The long sought improvements in efficiency promised by upgrading manned substations to monitored substations have been largely achieved.

It has taken many decades to get to this point. There has been a long evolution of technology and change that has brought SCADA technology this far. While substation automation is considered current technology, it is valuable to understand the steps in technological evolution and to recognize that some of that history is still in use in utilities today. The evolution in computer technology that helped drive the SCADA systems in their infancy has seen many significant changes. In the substation, micro-processor technology that gave birth to the intelligent electronic device (IED), opened the opportunity to combine functions and has significantly changed the landscape for the substation interface.

The SCADA system connects two distinctly different environments. The substation, where it measures, monitors, and digitizes; and the operations center, where it collects, stores, displays, and processes substation data. A communications pathway connects the two environments. Interfaces to substation equipment and communications resources complete the system. The substation terminus for traditional SCADA system is the *remote terminal unit* (RTU) where the communications and substation interface interconnect.

SCADA system RTUs collect measurements of power system parameters and transport them to an operations center where the SCADA master presents them to system operators. Predominantly, there are real and reactive power flow (watts and vars) voltages and currents. But other measurements like tank levels—pressures and tap positions are common to SCADA systems. These belong to the class of measurements termed analogs. Almost anything that can be viewed as a continuous variable over a range fits this category. Analog data is refreshed periodically so that the operator can be assured that data on this screen is relevant. The refresh rate is often dependent on the characteristics of the data being viewed and the communications resources available.

SCADA master stations monitor the incoming stream of analog variables and flag values that are outside prescribed limits with warnings and alarms to alert the system operator to potential problems. Data are screened for "bad" (i.e., out of reasonability limits) data as well.

SCADA systems also collect the state of power equipment such as circuit breakers and switches. These data are presented to the system operator, usually on graphical displays, to give the operator a view of the connectivity of the power system at any given moment. Various state change-reporting techniques have been used to report such changes for the system operator. These include flagging momentary changes, counting changes and time tagging them with varying degrees of resolution (sometimes as short as one millisecond).

SCADA systems almost always provide a means for the system operator to control power equipment. This includes circuit breakers, switches, tap changers, and generators. It may include some peripheral equipment in the substation as well.

In the operation center, a SCADA system has at least one computer, communicating to substations and/or generating stations collecting data, issuing control commands, and storing the incoming data. The system operator views data and messages through a set of displays on “view stations.” The displays allow the operator to control power equipment and make system changes through a screen dialog.

Besides these basic functions, the operations center computer archives data and displays selected data sets, such as trends and logs in special ways for the operators. More modern systems provide data to other areas of the utility enterprise in any number of different forms and services.

25.3.2 Energy Management System (EMS)

New Development of EMS/SCADA Technology. As the central nervous system of the power network, the control center—along with its energy management system (EMS) (see Fig. 25.5)—is a critical component of the power system operational reliability picture. The market’s shift, beginning in the late 1990s, from an investment strategy focused on improving capacity/reliability to one geared toward meeting the needs of a deregulating market impacted not only day-to-day infrastructure investment but also research and development. At the same time, utilities decreased EMS budgets even further because generation scheduling and optimization came to be viewed as a function of the deregulated side of the new market structure. Transmission entities therefore slashed their EMS budgets and staff, thinking that local independent system operators (ISOs) would assume

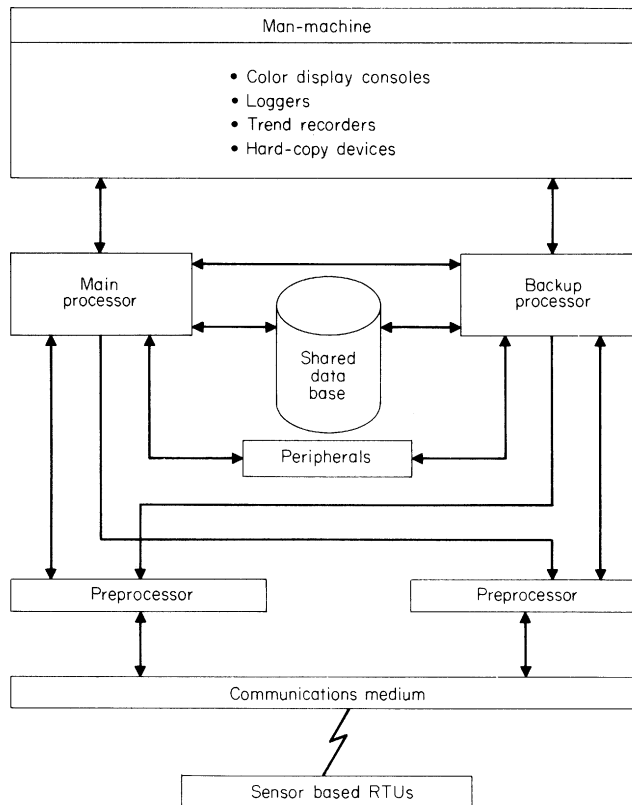


FIGURE 25-5 EMS architecture.

responsibility for grid security and operational planning. Those factors, combined with the fact that EMS technology has historically lagged behind the IT world in general, has created a situation where control room technology is further behind today than it has ever been.

The following important technology trends will come into play in the new EMS/SCADA solutions:

- *Visualization Control.* Control-room visualization today is still limited primarily to one-line diagrams, which are insufficient when it comes to today's needs to understand the availability of electricity at any given time and location and in understanding load, voltage levels, real and reactive power flow, phase angles, the impact of transmission-line loading relief (TLR) measures on existing and proposed transactions, and network overloads.

Three-dimensional, geo-spatial, and other visualization software will become increasingly indispensable as electricity transactions continue to increase in number and complexity and as power data, historically relevant to a contained group of entities, is increasingly communicated more widely to the ISOs and RTOs charged with managing an open grid. Not only do visualization capabilities enable all parties to display much larger volumes of data as more readily understandable computer-generated images, but they also provide the ability to immediately comprehend rapidly changing situations and react almost instantaneously.

Three-dimensional visualization is an invaluable tool for using abstract calculated values to graphically depict reactive power output, impacts of enforcing transmission line constraints, line loadings, and voltages magnitudes, making large volumes of data with complex relationships easily understood.

- *Advanced Metering Technology.* In this age of real-time information exchange, automated meter reading (AMR) has set new standards by which the energy market can more closely match energy supply and demand through more precise load forecasting and management, along with programs like demand-side management and time-of-use rate structures. Beyond AMR, however, a host of real-time energy management capabilities are now on the market, which, through wireless communication with commercial, residential, or industrial meters, enables utilities to read meters and collect load data as frequently as once every minute.

This enables utilities to better cope with dynamic market changes through real-time access to the critical load forecasting and consumption information needed to optimize decision support. The convergence of demand-response technologies and real-time pricing, wireless communications, and the need for more reliable and timely settlement processes are all drivers for enhanced metering capabilities. This, in turn, will create a demand for EMS solutions capable of handling much larger volumes of data and the analytical tools to manage this data.

- *More Stringent Alarm Performance.* The 2003 blackout drew attention to what has become a potentially overwhelming problem—SCADA/EMS has little or no ability to suppress the bombardment of alarms that can overwhelm control room personnel during a rapidly escalating event. In a matter of minutes, thousands of warnings can flood the screens of dispatchers facing an outage situation, causing them to ignore the very system that's been put in place to help them.

Although distribution SCADA has been able to take advantage of straightforward priority and filtering schemes to reduce the alarm overload, the transmission operations systems have not. This is because transmission systems are networked, and it is more difficult to analyze the alarms to determine what needs to be shown to help the operator reach a conclusion. Also, reaction time is not an issue in distribution, and there is more value in taking the time to locate the fault before taking action; short outages can be tolerated. Other industries, for example, telecom, networking, and refining have had good success with inference engines and other rule-based systems for diagnosing alarm conditions and providing operator assistance. These are worth a second look by the EMS fraternity today.

New analytical tools are needed in the EMS to enable operators to manage and respond to abnormal events and conditions. See Fig. 25-6.

- *Data Warehousing.* For many years, utilities have been archiving the operational (real-time) and nonoperational (historic) information captured by energy management systems. Today's thought leadership shift is to focus on how this archived operational and nonoperational data can be combined with emerging analytic functionality to meet a host of business needs, for example, to more readily identify parts of the network that are at the greatest risk of potential failure. If integrated

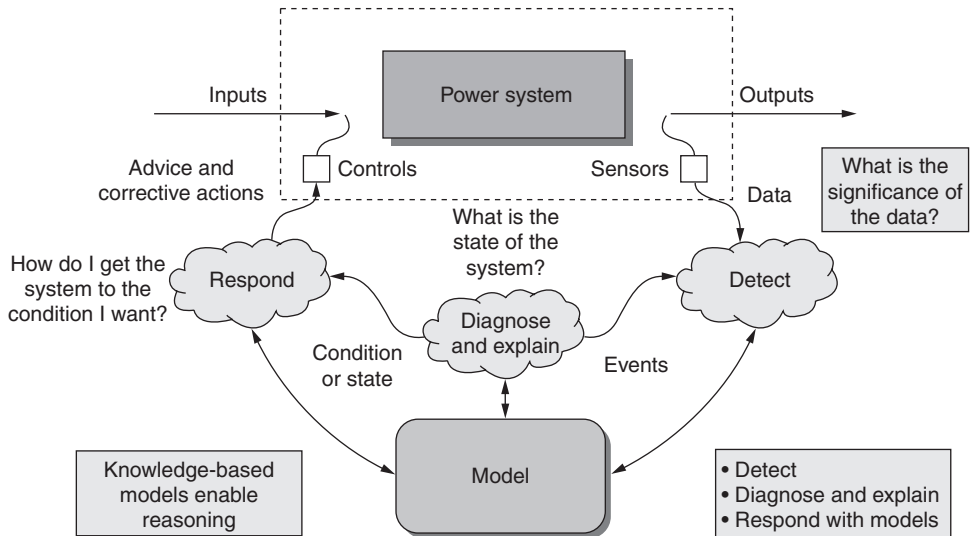


FIGURE 25-6 Real-time event management. (Courtesy of Gensym Corp.)

properly, heads-up information stored by these systems can also aid utilities in proactive replacement or reinforcement of weak links, thus reducing the probability of unplanned events.

A data mart is a repository of the measurement and event data recorded by automated systems. This data might be stored in an enterprise-wide database, data warehouse, or specialized database. In practice, the terms data mart and data warehouse are sometimes used interchangeably; however, a data mart tends to start from the analysis of user needs, while a data warehouse starts from an analysis of what data already exist and how it can be collected in such a way. Desktop access to the data each user needs to perform his or her job functions with an emphasis on business intelligence and knowledge management.

- *Communication Protocols.* EMS systems must have the capacity to talk to “legacy,” i.e., preexisting, remote terminal units (RTUs) and, thus, are severely handicapped today in that many still rely on serial RTU protocols that evolved in an era of very limited bandwidth. As a result, most EMS solutions in use today are unable to exploit breakthroughs in communications, in particular, secure communications such as encryption and validation. This will need to change. Eventually, the need for encrypted, secure communications to the RTU, combined with adoption of substation automation and substation computers, may lead to the end of RTU protocols as we know them today and adoption of a common information model (CIM)-based data model for the acquisition of field data.
- *Enterprise Architectures.* To achieve the benefits offered by the technologies described here, EMS solutions need to be able to take advantage of modern enterprise architectures (EAs). EMS systems are typically not included as part of utility EA initiatives, but as their importance becomes readily apparent, this will change. Though EA definitions vary, they share the notion of a comprehensive blueprint for an organization’s business processes and IT investments. The scope is the entire enterprise, including the control room, and, increasingly, the utility’s partners, vendors, and customers.

Though no industry-standard technical/technology reference model exists for defining an EA, it is clear that component based software standards, such as web services, as well as popular data-exchange standards, such as the extensible markup language (XML), are preferred, as are systems that are interoperable, scalable, and secure, such as Sun Microsystem’s Java 2, Enterprise Edition (J2EE) platform, or Microsoft’s .Net framework.

Workflow	UML		
Semantics	Biz talk, XML.org OAGIS, UIG-XML, CCAPI, CIM		
Format	XML		
Interaction	MSFT .Net	J2EE	CORBA
Security	(COM+)	(EJB)	
Integrity			
Transport	IP		

FIGURE 25-7 Integration standards.

It is also clear that frameworks and initiatives, such as the Zachman framework, Federal Enterprise Architecture Framework (FEAF), The Open Group Architecture Framework (TOGAF), and Rational Unified Process (RUP), will strongly impact how enterprise architectures for utility control operations are defined and implemented. See Fig. 25-7. By using shared, reusable business models (not just objects) on an enterprise wide scale, the EA provides tremendous benefits through the combination of improved organizational, operational, and technological effectiveness for the entire enterprise.

- *Web Services Architecture.* There are no EMS deployments today that take advantage of modern Web services architecture, although the architecture is providing tremendous benefits to businesses around the world and holds big promise for control room operations.

Like object-oriented design, Web services encompass fundamental concepts like encapsulation, message passing, dynamic binding, and service description and querying. With Web services architecture, everything is a “service,” encapsulating behavior and providing the behavior through an API that can be invoked for use by other services on the network. Systems built with these principles are more likely to dominate the next generation of e-business systems, with flexibility being the overriding characteristic of their success.

As utilities move more of their existing IT applications to the Internet, a Web services architecture will enable them to take strong advantage of e-portals and to leverage standards, such as XML; Universal Description, Discovery, and Integration (UDDI); Simple Object Access Protocol (SOAP); Web Services Definition Language (WSDL); Web Services Flow Language (WSFL); J2EE; and Microsoft.NET.

The dispatcher’s interface to the EMS system is through color display terminals used to display on-line diagrams and tabular displays. These displays are updated cyclically or whenever a change is detected. Various data and operating conditions are highlighted with color. The dispatcher uses the displays to interact with the system such as acknowledging an alarm, changing operating limits, controlling devices, determining system status, or executing a program.

The major functions performed by an EMS system are shown in Table 25-1. The types of processing that these functions include are cyclic work that must be completed within a specific cycle, event-driven work that results from random alarms and events that occur on the network, real-time or demand work that has specific response-time requirements, and interactive work which is dispatcher-initiated that also has response-time requirements.

TABLE 25-1 EMS Functions

Network surveillance and control • Network data acquisition • Data conversion, limit checking • Alarm processing • Logging and reporting • Load-shedding power device control	Generation commitment and control • Automatic generation control • Economic dispatch • Load forecasting • Unit commitment • Reserve monitor
Interchange management • Production costing • Transaction evaluation • Interchange scheduling • Interchange accounting	System security • Network status • State estimation • Contingency analysis • Interactive load flow • Training simulator

Network Surveillance and Control. This consists of continuous scanning of remote sensor-based units, acquiring all key network and generation data on a 2-s cycle, checking the data for problems, and presenting the status of the network to the dispatcher through displays. The control function allows the dispatcher to take selective control action on power system devices such as circuit breakers. Frequently these functions are called SCADA (supervisory control and data acquisition).

Network data acquisition programs acquire power system data through periodic scanning of local and remote sensors attached to RTUs. The raw data are checked for missing or invalid data before being sent to the central processors by the communications front end. Retransmissions are requested for missing status data.

Data conversion and limit checking programs are used to process the raw data. The data are scaled and converted to engineering units and stored in a database for use by application programs. Reasonability checks are made on the data and values not found to be within limits cause alarms.

Alarm processing programs generate alarms for scanned data and calculated results as changes of network status are discovered, limits are exceeded, or other invalid conditions are encountered.

Logging and reporting programs store selected data in historical log files, where they are available for analysis through displays and reports.

Power device control functions provide for the control of power system devices and for the placement or removal of device tags. Control actions made by the dispatcher to activate power devices are verified, then forwarded through the network to the proper destination.

Load shedding provides rapid access to data for guiding the action of the dispatcher during abnormal operating conditions. Typical of the data that are displayed is the amount of load relief that can be obtained through emergency output of all generating sources, generation requirements, interruptible loads, load curtailment, voltage reduction, and emergency backup through tie lines.

Generation Commitment and Control. This consists of a set of programs used to optimize the production and delivery of power for fuel savings.

Automatic generation control regulates generator output to match the load in order to maintain the frequency in an area and the sum of all active tie-line power exchanges with neighboring power systems. This program executes cyclically every 2 s.

Economic dispatch minimizes the cost of meeting the energy requirements of the system over a period of time and in a manner consistent with reliable service. Desired generator settings are computed and fed to the automatic generation control program. This cyclic program executes every 5 min and also on demand.

Load forecasting computes the total system hourly load for a specified number of days. It provides an adaptive forecasting system based on observed values of demand and estimated weather conditions. The program generally consists of three mathematical models. A load forecasting model uses past load data to compute hourly load forecasts. A weather forecasting model computes hourly weather forecasts based on past weather history. A weather correction model uses telemetered values of load and weather conditions to correct the forecast. The dispatcher may optionally enter these values through a display.

The historical load and weather data are stored and maintained in files which also contain special events that affect load such as holidays or unusual weather phenomena.

Unit commitment determines a schedule for optimal startup and shutdown of thermal units which minimizes unit startup costs subject to generation objectives, predicted area requirements (load forecast), security (spinning reserve requirements and off-system capacity), and operational constraints (unit minimum up and down times, limits, ramp rates, maintenance and derating schedule). It minimizes the operating costs of the dispatchable generating units. The total dispatchable generation is the sum of the load forecast and net scheduled interchange minus the total nondispatchable generation. The operating cost is defined as the sum of production, startup, shutdown, and maintenance costs. Production cost is calculated by the use of input and output curves adjusted by fuel prices. Transmission losses are also considered using one or more sets of penalty factors. Transmission limits are considered with simple approximations.

The output of unit commitment is the hourly unit schedule. Several sets of schedules (or strategies) may be output for operator review and selection. The output is stored and made available to other applications such as transaction evaluation. This program is executed two times a day.

Reserve monitor calculates the available operating reserve necessary to meet company operating policies. Typically, a spinning reserve, 30-min reserve, and 2-h reserve are computed. This program executes cyclically every 4 min or on demand. The dispatcher is alerted when there is inadequate reserve.

Maintenance scheduling assists operating personnel in scheduling generator maintenance in an optimum manner. It generates a maintenance schedule while taking into account constraints and limitations on available resources required to perform maintenance work. The maintenance schedule indicates when particular generating units will be out of service (unit outages). Maintenance is performed routinely at desired intervals or may be required because of unexpected forced outages.

During the maintenance of a given generator, the outage of this unit is compensated for by other capacities in the power system. This is done by maintaining a level of system reserves. The scheduling of generator outages is performed in a manner which maintains a flat megawatt reserve level or a consistent level of probabilistic level of risk, i.e., probability of emergency procedures.

Interchange Management. Formal and informal interchange agreements may exist between neighboring companies. Operating as an interconnected system has economic and security advantages. While many power pools have control centers to manage the interconnection, most companies prefer to manage, or at least monitor, their own interchange of power. The interchange management programs provide the dispatcher with the ability to make good deals with the neighbors. These interactive routines allow the dispatcher to evaluate a buy or sell transaction before being committed to it. Once initiated, the interchange scheduling program automatically schedules the transaction through the automatic generation control program.

Production costing provides the capability to compare a change in interchange with the current schedule. The program always starts by accessing a study file. The calculations are based on current or forecast system load and a proposed interchange schedule entered by the operator.

Transaction evaluation calculates the costs and savings associated with the sale and purchase of power with a selected interconnected company. The program can be used to evaluate past, present, and future operation costs. A production cost calculation is generally included as a part of this program or may be an independent routine.

For evaluating transactions, the transaction evaluation program computes the costs of savings of a proposed transaction by comparing the production costs computed from two economic dispatch calculations: a base economic dispatch calculation for the operating conditions with and without the proposed transaction.

The transaction evaluation program usually can be executed in two modes which specify the starting point for all calculations. These two modes are whether the unit commitment program will be called or not. Essentially, the two options determine how the generation schedule is to be determined. Mode A (also called *economy A*) is executed without unit commitment. Current system load, interchange schedules in study file, and existing unit commitment form the starting conditions. Mode B (also called *economy B*) is executed with unit commitment and is used for transactions in the future.

Interchange scheduling is used to process and display each scheduled transaction with interconnected utilities. It computes the total net scheduled interchange as a function of time for use by the automatic generation control program. This calculation considers the start and stop times, generator ramp rate, magnitude, and direction of each active interchange transaction. Interchange schedules and cost information may be logged and displayed.

Interchange accounting provides the capability to account for electric power in the system. This electric power, in the form of measured, calculated, or scheduled megawatts, includes megawatts which are generated, consumed, lost, passed through, sold, and purchased. It includes functions for logging, displaying, reporting, and updating data recorded by the realtime system.

System Security. These programs help to reduce the chance of a major outage or blackout condition. They operate on a study database which has been cleansed of missing data and metering errors by the network status and state estimation programs.

Network status determines the current configuration of the network based on the status of circuit breakers and disconnect switches obtained from the real-time data and from manually entered status information for devices not telemetered. The program is executed periodically, whenever a status change is detected, or on dispatcher request. In addition, the program develops the corresponding mathematical model of the network using the impedance data for the current base load flow or state estimation case. The model will be used in the subsequent calculation of real-time system conditions using the load flow or state estimation programs.

State estimation determines the current state of the power system, including voltage levels and power flows, and calculates loss factors for use by the economic dispatch program for generation scheduling. It filters real-time measurements to detect and eliminate known errors; estimates expected values of the next real-time measurements; and determines the current network configuration. It corrects the mathematical model of the current network configuration. Thus the state estimation program acts as a filter between the raw real-time data and the real-time data requirements of other security applications. The state estimation program is executed whenever the network status program detects a change, periodically, or on dispatcher request.

Contingency analysis computes the potential effect of contingencies involving the loss of generation and transmission facilities. A specific set of predefined contingencies is analyzed on a cyclic basis. It simulates a contingency and calculates the changes in bus voltages and power flows resulting from the contingency. The base conditions for this calculation are the bus voltages or power flows obtained from the load flow program.

Interactive load flow (ILF) allows the dispatcher to perform load flow studies for a scheduled outage or analyze corrective actions after an unexpected outage. ILF uses real-time data to project bus loads in a network. A bus is a connection where power lines change direction or voltage. A bus load is the load at this point. The ILF program stores mathematical models of the present and planned networks. A color display terminal is used to display one-line diagrams of these models. Colors are used to differentiate voltages, heavily loaded lines, bus voltages outside of limits, and open circuit lines. The dispatcher uses a light pen or mouse together with the terminal keyboard to retrieve previous load flow cases, make modifications, create displays, execute load flow cases, and store them.

Training simulator uses a model of the power network to produce realistic reactions to a dispatcher in training. This function is usually run on the backup central processing unit (CPU). The program can operate in either of two modes: monitor or simulation mode. In monitor or playback mode, the simulator reflects the changing status of the power system during the time period when a playback tape was written. The trainee can view displays, thus monitoring power system changes, but cannot take any control action.

In simulator mode, the trainer can input system changes, and the trainee is allowed to perform control actions. The simulator software will reflect the state of the power system based upon the changes input and control actions taken. In this manner the trainee can operate the control system without affecting the true state of the power system.

Customer response systems control centers are a critical link in responding to customer complaints and reacting to outages. Customer information systems (CIS), used for many business and commercial purposes, are increasingly being combined with the engineering and operations information in order to speed repair crew dispatch and reduce outage times. Work orders, repairs, and inspections are increasingly being merged with inventory, warehouse, and engineering records to reduce costs, speed reaction times, and improve technical performance.

25.3.3 Power Plant Monitoring and Control

This application approaches the traditional process control application. Several applications such as fuel monitoring and performance calculations increase the requirement for the data processing resource. The three major computer systems for fossil power plant monitoring and control are described below.

Process Control System. This is a closed-loop control system which takes its direction from EMS and automatically collects plant data by reading instruments. Physical and electrical parameters associated with the boiler, turbine, and generator are monitored on a continuous cyclic basis. Alarms and events are logged, and control of pumps, valves, and switches for routine functions and for startup and shutdown are provided.

Plant Monitoring System. This is strictly a data-collection system for fuel monitoring, performance calculations, and balance-of-plant calculations; no control actions are performed. Data are stored and retrieved as required to prepare reports and perform analysis. These reports include those required by the plant management, load dispatchers, and planning and engineering groups. Periodic reports are prepared to reflect plant operation. Unit incremental generation cost is determined periodically by collecting data that continuously reflect actual operating conditions. This information is transmitted to the dispatcher for use in load dispatching.

Operational Monitoring System. This is used by plant operators to enter manually collected operational data for record keeping, report writing, and engineering analysis. In addition to these systems, the power plant also may use mini- or microcomputers for security systems, environmental systems, controlled access systems, and chemical analysis systems.

25.3.4 Power Plant Maintenance

Power plant maintenance stores pertinent plant maintenance information for analysis of maintenance costs and evaluation of equipment performance. The interactive portion of the system provides power plant personnel with the capability to enter problem data, planning data, and work execution data. Approval and verification functions are at each step of a work order's progress from problem description through work completion and commitment to history. Interactive functions also are provided for entry and maintenance of an equipment database and for access to equipment history.

The batch portion of the system provides for moving completed and rejected work from the active work database to the equipment history database. Batch functions are also used for work backlogs, scheduled work, and other reports.

Because of its varied data requirements, the maintenance information system also has interfaces to other computer systems in the power company. These are the materials-information system for equipment stocking levels, the personnel information system for labor resources, and the general accounting system for cost tracking. Additionally, text processing services are frequently used.

25.3.5 Fuel Management

Fuel is the single largest expenditure in power-plant operations. Operating support personnel must plan for both short-term (1 year) and long-term (5+ years) fuel availability. Thus control and improvement of fuel cost represent the most substantial contribution to the overall economy of power production. The system is used to administer the procurement of coal and oil. It facilitates the monitoring, reconciliation, and performance of fuel contracts. Accounting functions are used for fuel purchases, transportation costs, fuel usage, and inventory value. Also included are short- and long-term cash flow projections and managerial and regulatory reporting capabilities. The overall fuel management application is an integrated model of the load forecast, generation scheduling and dispatch, and fuel allocation with an objective of optimizing fuel contracts. This application is used routinely with growth and on demand as system perturbations occur.

25.3.6 Load Management

The objective of the load management application is to improve the load factor (ratio of average load to peak load) and to be able to shed selected load during emergency conditions. Most utilities have pilot tested some form of load management. The pilot solutions range from consumer guidance (voluntary) to complete control and metering of the consumer's load.

The benefits of load management have been shown to be enhanced by combining two-way utility to customer communications and control into a distribution automation system. An automated distribution system can have valuable additional functions such as automated meter reading, performance monitoring, and quality-of-service improvement.

Load Curtailment System. This scheme employs one master computer at the power company and several computers at major industrial and commercial load centers. In this scheme there is a limited sensor-based data-acquisition requirement and no closed-loop control. Reduction of load will be manual.

Automatic Meter Reading and Load Management. This hierarchical approach employs the corporate customer information system and the EMS system to direct and receive the meter readings, an intermediate level to serve as a communication concentrator, and an intelligent data control unit to scan remote transponders at the meter locations.

25.3.7 Nuclear Data Center

Functionally, the nuclear data center consists of three systems (Table 25-2), which are described below.

Operational System. This consists of real-time and on-line monitoring of various subsystems in a nuclear plant. The plant process computer system in a nuclear plant is usually provided by the reactor vendor and integrated with the reactor. Additional monitoring facilities are now required by the Nuclear Regulatory Commission (NRC). One specific monitoring system is named the *emergency response information system*, which is now a firm requirement for all operating nuclear plants and a license requirement for plants under construction. It has the following components:

- *Safety parameter display system.* This provides additional monitoring and display facilities to the primary plant control room. The additional facilities provide continuous monitoring of critical parameters.
- *Technical support center.* This is a separate facility and staff within the plant to assist the primary plant control room during emergency conditions.

TABLE 25-2 Nuclear Data Center Functions

Operational	
Plant process computer system	
Operator training simulator	
Plant security system	
Emergency response information system	
Radiation monitoring system	
Technical	
Fuel shuffling	Radioactive waste control
Fuel management	Meteorological/environment
Refueling outage scheduling	Chemical laboratory
Quality assurance	Health physics
Start-up testing	Technical services
Administrative	
Maintenance	Nuclear records management
Materials management	Financial control
Licensing	Plant operation
Document control	Personnel
	Training

- *Emergency operations facility.* This is a separate facility and staff located off the plant site but in proximity to the plant. It will manage the overall emergency response and evaluate actual and potential radiological releases.
- *Nuclear data link.* This routes cyclic data from the plant to the NRC headquarters through a communication link. The critical data will be used to monitor an accident, to evaluate emergency conditions, to advise and assist the licensee, and to inform the general public.

Administrative System. This is used for maintenance and backup of the operational system. Storage and information retrieval systems are used for the storage and retrieval of large amounts of data as encountered in nuclear records management. These systems provide interactive direct access to, and fast scanning or searching of, large numbers of articles, reports, contracts, laws, general directives, or abstracts of publications.

Technical System. This is used for large simulation and nuclear fuel management programs. Computer programs simulating nuclear core physics in various levels of detail are presently being used for analysis, leading to continual improvement and enhancement of nuclear plants. These programs are used not only in the design of cores for nuclear reactors but also for the planning and decision making regarding fuel burnup and associated electrical generation for nuclear units. Core refueling schedules are of vital concern. Safety analysis for emergency situations is another area in which the simulation programs are used. Nuclear fuel management programs are used for the design of nuclear reactors and for nuclear fuel management calculations.

25.4 ENGINEERING COMPUTING TRENDS

Costs. Today the cost of the engineering user is 8 to 50 times the cost of the computer that the engineer uses. This range depends on the level of the user and the type of processing: machine-intensive

(compiling, executing) or human-intensive (editing, scrolling). It is no longer cost-effective to economize on computing resources required by the engineering user.

Personal Computing. Batch-job and central processing is rapidly being replaced by networked or individual personal computers and workstations. The fast performance and low cost of this equipment are a perfect complement to modern interactive, graphics-oriented software, which combine to greatly improve engineering productivity and effectiveness.

Networks. High-speed networks allow easy communication of data, results, and messages, leading to an integrated set of applications spanning functions and levels of the company. Ethernet and token-ring systems and communication protocols such as TCP/IP provide versatile and very high speed communications between diverse computers.

Languages. Most engineering computer applications are written in FORTRAN because of the long-time popularity of this language. New applications and graphics user interfaces (GUI) are usually written in C or the object-oriented C++ language. Graphics interfaces use special facilities such as Windows, MOTIF, and OpenLook.

On-Line Reporting. This has replaced manual reporting of data. Although text processing systems are used to generate documents, text information can also be transmitted, distributed, and stored electronically to reduce the proliferation of paper documents.

Results Selection and Editing. This is now performed by scrolling a display instead of printing all results and sifting through reams of paper.

Automated Data Flow. The trend is to maintain one set of data that is available to all users. These data are protected by appropriate security features and procedures like any other corporate resource. However, the intent is to make common data available to all users and allow the appropriate users to update the common data. This common database leads to accuracy, avoids duplication, and avoids loss of labor due to the reentry of data.

Productivity Aids. While most of the computer applications that the engineer uses are complex programs, the productivity of the engineer is also increased by simple, direct tools for text processing, graphics, and project control. These tools are interactive and require a minimum of effort to use. These tools help the engineer make notes, drafts, lists, sketches, and establish personal meeting or project schedules.

Computer Configurations. Computer configurations such as shown in Figs. 25-8 and 25-9 are used to support engineering functions. Although the centralized computing approach has traditionally been used, the trend is to a distributed approach in which a separate engineering information center is assigned strictly to engineering work.

Engineering User Service Objectives. Engineering users require three categories of computing support:

1. **Performance requirements.** Less than 0.4-s response time is required for human-intensive work at a terminal. Longer response times reduce concentration and increase frustration. A predictable response time is required for machine-intensive work. Consistent timings for load flow are expected when operating under deadlines. High-bandwidth terminals are required to support Windows graphics user interface (GUI) color graphics applications, which are used to speed work flow and to reduce volumes of data to a presentation of results in a form that can be readily assimilated.

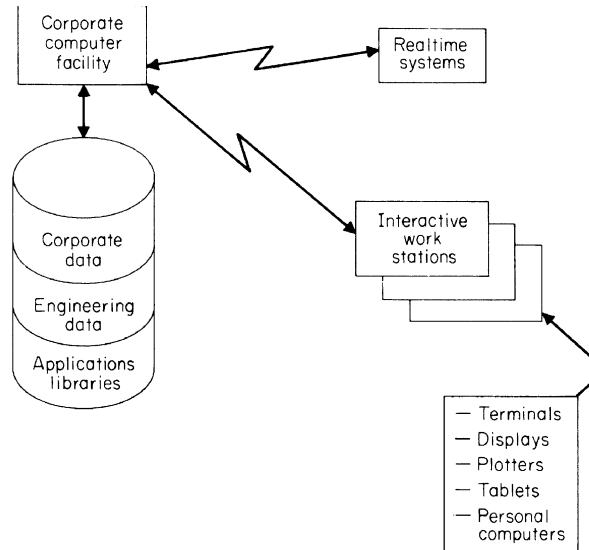


FIGURE 25-8 Power engineering centralized architecture.

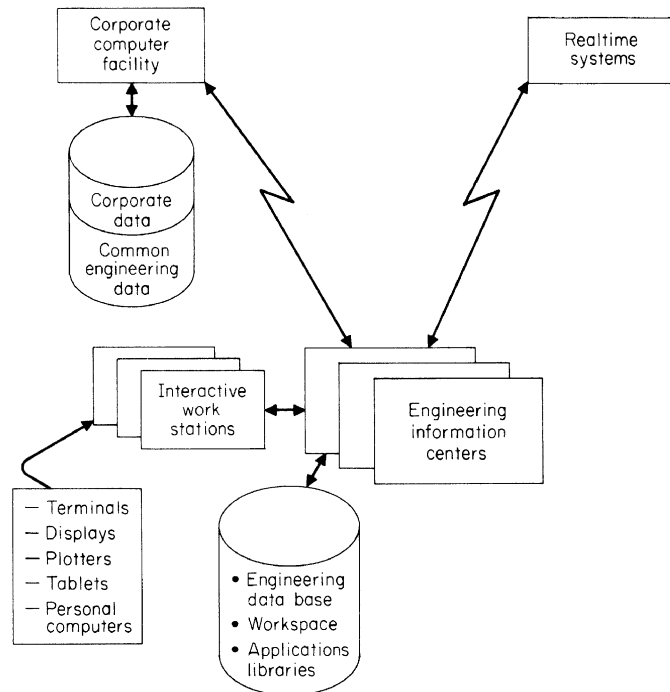


FIGURE 25-9 Power engineering distributed architecture.

2. *Technical support requirements.* The engineering user requires a minimum of system programming knowledge to use the computing system. Included in this are user-friendly selection panels, menus, aids, and help functions; a library of programming tools, languages, and application packages, all of which are maintained by the central data processing department; and training facilities and technical support to assist engineers with the use of computing resources.
3. *Operational support requirements.* Security features and operational procedures are required to protect the user's data and access to the computing system. Included are security features such as password protection of user data files and sign-on's and operational procedures to provide backup of user data and prevent its destruction or loss.

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